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NAVAL AIR WARFARE CENTER AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND

TECHNICAL REPORT

REPORT NO: NAWCADPAX/TR-2001/9

FLASHJET® QUALIFICATION TESTING FOR LIFECYCLE DEPAINTING OF ROTARY WING FUSELAGE SKINS

by

Joseph Kozol
Steven Hartle
Paul Raley
Thomas Berkel, The Boeing Company

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14. ABSTRACT This program evaluated the effects of FLASHJET® life cycle paint stripping on the high cycle fatigue behavior of two aluminum alloys used for fatigue critical helicopter structure. Based on the completion of five repeat paint and strip cycles, the fatigue life of 0.025 in. thick 2024-T3 or 7075-T6 aluminum is not degraded by stripping to the substrate with the FLASHJET® paint stripping process, when operated within the process parameters operating range tested.					
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INTRODUCTION

The effects of the Boeing FLASHJET® paint removal process on aircraft substrates have been evaluated by U.S. Air Force and Navy programs teaming with the Boeing Company (references 1, 2, 3, and 4). Test results showed that the process can be used with no damaging impact on the mechanical properties of thin structural aluminum alloys or on graphite/epoxy composite structures. With the accumulation of an extensive data base, NAVAIRSYSCOM authorized use of the process for the removal of organic coatings from metallic and monolithic polymer matrix composite fixed wing aircraft surfaces.

The Environmental Security Technology Certification Program awarded the U.S. Army Environmental Center a program to demonstrate and validate the FLASHJET® process on multiservice rotary wing and ground vehicle applications. In support of this effort, the Materials Division at NAWCAD Patuxent River, Maryland, conducted high cycle fatigue tests on 0.016 and 0.025 in. aluminum alloys after FLASHJET® stripping. Results were acceptable to allow a one time FLASHJET® strip of an operational SH-60 helicopter, in accordance with the parameters used in the strip tests. This report describes high cycle fatigue testing to support the life cycle (5-strip cycles) use of the FLASHJET® process on 0.025 in., 7075-T6 and 2024-T3 aluminum alloys.

OBJECTIVE

The objective of this program is to support qualification of the FLASHJET® process for life cycle paint stripping of fatigue critical H-60 helicopter airframe structure. The test program addresses the high cycle fatigue behavior of 0.025 in. thick 7075-T6 and 2024-T3 aluminum alloys after five cycles of painting and stripping. The S-N fatigue life will be compared to that of unpainted, unstripped material.

PANEL PREPARATION

Materials used in this program, representative of H-60 helicopter fuselage skin, were as follows:

a. 0.025 in. aluminum alloy alclad 7075-T6

b. 0.025 in. aluminum alloy alclad 2024-T3

Eight inch square panels were sheared from large sheets at NAWCAD Patuxent River and the rolling direction marked to orient the longitudinal axis of fatigue test specimens. Panels were identified as 7 (for 7075) or 2 (for 2024) and serialized. All panels were solvent cleaned, chromate conversion coated per MIL-C-5541 Class 1a and divided into two groups identified as:

a. Group A Control - This group received the same thermal aging treatment applied to the test group but was not painted and not stripped.

b. Group C Paint and Strip - Initial painting was performed at NAVAIRSYSCOM as follows:

   (1) Epoxy Primer, Waterborne, MIL-PRF-85582C, Ty I, 1.0 ±0.2 mils

   (2) Polyurethane Topcoat, MIL-PRF-85285C, Ty I, 2.0 ±0.2 mils, color No. 36375

Painted panels were air dried for 7 days at ambient temperature and aged (along with Group A panels) for 7 days at 150°F. The Group C panels were then sent to Boeing-St. Louis for 5 stripping cycles, with paint to be removed to the substrate at each strip cycle as a worst case condition. After each stripping, panels were solvent cleaned and painted at Boeing-St. Louis with the same thicknesses of epoxy primer and polyurethane topcoat as described above. Following repaint, panels were again air dried at ambient temperature for 7 days followed by an artificial aging cycle for 7 days at 150°F. Average paint thicknesses are shown in table 1.

Table 1: Average Prestrip Coating Thickness (mils)[1]

Paint/Strip Cycle	2024-T3 Panels	7075-T6 Panels
1	2.12	2.15
2	4.48	4.54
3	3.74	3.81
4	3.16	3.63
5	3.76	4.04

NOTE: (1) Coating thickness measured with QuaNix 1500 coating thickness gage.

FLASHJET® STRIPPING PROCEDURE (CYCLES 1-5)

Panels were mounted to the stripping table and clamped in place along the two edges of the panel corresponding to each end of the rolling direction. FLASHJET® pass direction was perpendicular to the rolling direction of the panels so that the FLASHJET® process was focused on the test area of the subsequently machined fatigue test specimens.

Paint was removed to the substrate on each of the five stripping cycles. Removal to the substrate for these aluminum panels consisted of removal to a maximum of 0.0002 in. (0.2 mil) paint film. Paint is normally removed to primer with the FLASHJET® process. Stripping to substrate represents a more severe condition than actual practice.

FLASHJET® stripping parameters were developed on spare, practice panels. Although there is a wide range of acceptable stripping energy, panels were processed using high input voltage to expand the allowable FLASHJET® stripping parameters on rotary wing fuselage skins and demonstrate the lack of thermal damage to the aluminum substrates without limiting the associated short pulse peak temperature. Processing parameters used maximum input voltage on the initial pass(es) to remove the topcoat, and were reduced to 2,000 - 2,100 V for the final pass(es) to the substrate. For most stripping cycles, one pass was made at 2,300 V and a second pass was made at 2,000 V. Strip cycle No. 1 required a third 2,000 V pass on 2 panels to achieve the required substrate condition. Strip cycle No. 2 required two initial passes at 2,300 V on all panels and a third pass at 2,000-2,100 V on some panels to achieve the substrate condition. Other parameters remained constant through the five stripping cycles, including a 3 Hz flash repetition rate, 0.75 in./sec stripping head traverse rate, 47.5 ±2.5% CO_2 feeder rate, and 150 ±10 PSI pelletizer pressure. Adhesive-backed temperature indicator stickers that change color at predetermined temperatures were applied to the backside of panels to provide a simple method of measuring, monitoring, and documenting temperatures. A maximum of 12 FLASHJET® passes were needed on some panels to complete 5 FLASHJET® depainting cycles. Of those 12 passes, 8 resulted in peak substrate temperatures greater than 300°F. The highest peak temperature recorded on any one pass was 370-400°F (three panels, strip cycle No. 1, second pass).

A summary of the FLASHJET® stripping parameters, number of stripping passes and resultant temperatures are shown in table 2.

Table 2: FLASHJET® Stripping Parameters

Strip Cycle	First Pass		Second Pass		Final Paint Thickness[5]
	Input Voltage	Peak Temp (°F)[1]	Input Voltage	Peak Temp (°F)[1]	
1[3]	2,300 V	250 – 270°F (12%)[2] 270 – 300°F (82%) 300 – 330°F (6%)	2,000 V[3]	330 – 350°F (75%) 370 – 400°F (25%)	< 0.2 mils
2[4]	2,300 V	200 – 230°F (33%) 230 – 250°F (67%)	2,300 V[4]	200 – 230°F (17%) 250 – 270°F (33%) 270 – 300°F (25%) 300 – 330°F (25%)	.07 mils (avg.)
3	2,300 V	200 – 230°F (50%) 230 – 250°F (50%)	2,000 V	330 - 350°F (50%) 350 – 370°F (50%)	.06 mils (avg.)
4	2,300 V	200 – 230°F (100%)	2,000 V	300 – 330°F (13%) 330 – 350°F (31%) 350 – 370°F (56%)	.04 mils (avg.)
5	2,300 V	200 – 230°F (38%) 230 – 250°F (50%) 250 – 270°F (12%)	2,000 V	300 – 330°F (25%) 330 – 350°F (63%) 350 – 370°F (12%)	.04 mils (avg.)

NOTES: (1) Hermet® temperature indicator points (°F) – 200 / 230 / 250 / 270 / 300 / 330 / 350 / 370 / 400.

(2) Temperature range 250 – 270°F (12%) means that the Hermet® temperature point at 250°F was triggered, but the 270°F point was not, and that 12% of the panels achieved this same peak temperature range.

(3) Cycle No. 1 third pass at 2,000 V required on panels 7-2 and 7-4 to achieve substrate condition (peak temp 330-350°F).

(4) Cycle No. 2 third pass required on 10 panels to achieve substrate condition:

2,000 V (panel 7-8)	Peak temperature range 300 – 330°F
2,050 V (panels 2-4, 2-5, 2-6, 2-8, 2-9, 7-6, and 7-9)	Peak temperature range 300 - 330°F (43%) Peak temperature range 330 – 350°F (29%) Peak temperature range 350 – 370°F (29%)
2,100 V (panels 2-2, 2-3)	Peak temperature range 330 – 350°F

(5) Paint thickness measured by QuaNix 1500 coating thickness gage.

HARDNESS/CONDUCTIVITY HISTORY

Aluminum panels 2-1 (2024-T3) and 7-1 (7075-T6) were designated as hardness/conductivity test panels. They were processed with all the fatigue test panels simultaneously, going through five paint/age/strip cycles. However, before and after each FLASHJET® strip cycle, the two panels were tested for hardness and electrical conductivity. Hardness measurements were taken using a Digital Versitron, 15-T scale. Conductivity measurements were taken with a Zetec M1Z-22, except poststrip cycle No. 3 measurements were taken with an NDT-17. Panels 2-13 and 7-13 were used to "backup" the 2-1 and 7-1 test panels to provide a 0.50 in. effective thickness. Figure 1 graphically displays the average hardness and "stacked" conductivity readings of the test panels before, during and after the 5-cycle processing. Each hardness reading represents the average of 24 individual readings and each conductivity reading represents the average of 8 individual readings. No stacked conductivity readings were taken at poststrip cycle No. 1. The hardness and conductivity history profiles do not indicate that any heat damage has occurred. All

All hardness and conductivity readings were within requirements for the materials, and showed no discernible increasing or decreasing trend during the 5-cycle paint/strip history.

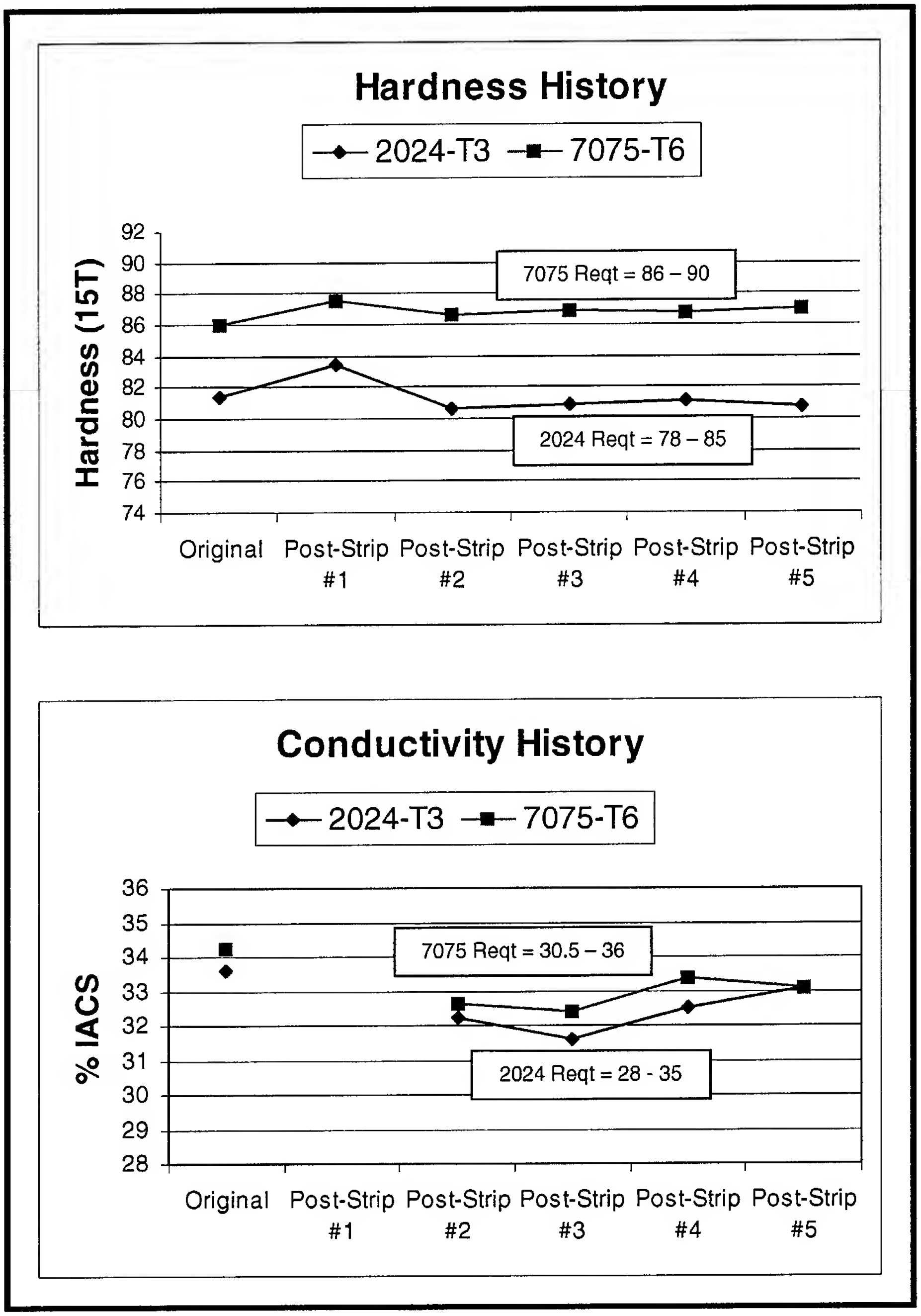

Figure 1: Hardness and Conductivity of Stripped Panels

HEAT DAMAGE TO ALUMINUM ALLOYS

There is reference material that substantiates the relationship between conductivity, hardness, and strength to allow evaluation of heat damage of aluminum alloys as related to exposure time and exposure temperature. Heating 2024-T3 and 7075-T6 aluminum alloys above 300°F for sufficient time results in a drop in hardness and strength and a rise in conductivity. For 7075-T6 alloy, it takes 2 min cumulative exposure time at 400°F or 78 min at 325°F to observe a slight change in hardness; and it takes about 1 hr at 400°F and 100 hr at 325°F before hardness drops below minimum acceptable values (reference 5). For 2024-T3 alloy, it takes 100 hr at 400°F for the material to degrade to the minimum acceptable ultimate tensile strength, and over 1,000 hr at 300°F (references 5 and 6).

Each pass with FLASHJET® heats the substrate for only a few seconds, so that many repeated painting/depainting cycles would still heat the substrate for far less cumulative time than that required for damage, as confirmed by the hardness and conductivity profiles. The peak substrate temperature from each FLASHJET® pass is achieved in about 2 msec (.002 sec) and takes only a few seconds for cooling to hand-touch temperature. For the panels stripped in this phase, 8 of 12 passes made in the 5 FLASHJET® stripping cycles reached a peak temperature between 300-400°F. Total exposure time above 300°F was an estimated 40 sec, (worst case) maximum. Total exposure time above 370°F (one pass) was on the order of 5 sec, (worst case) maximum. So the total exposure time at high temperatures due to many, repeated FLASHJET® passes does not approach the exposure time needed to initiate hardness or strength degradation.

FATIGUE TESTING PROCEDURE

Upon completion of five strip cycles at Boeing-St. Louis, panels were returned to NAWCAD Patuxent River and machined into 2 x 8 in. longitudinal dogbone type specimens, with drilled and reamed center holes of 0.100 in. diameter, as shown in figure 2. Constant amplitude, tension-tension fatigue testing was performed according to ASTM E466, at stress ratios of 0.1 and 0.5 and a frequency of 40 Hz. Failure condition was specimen fracture. Run out was in excess of 10 million cycles.

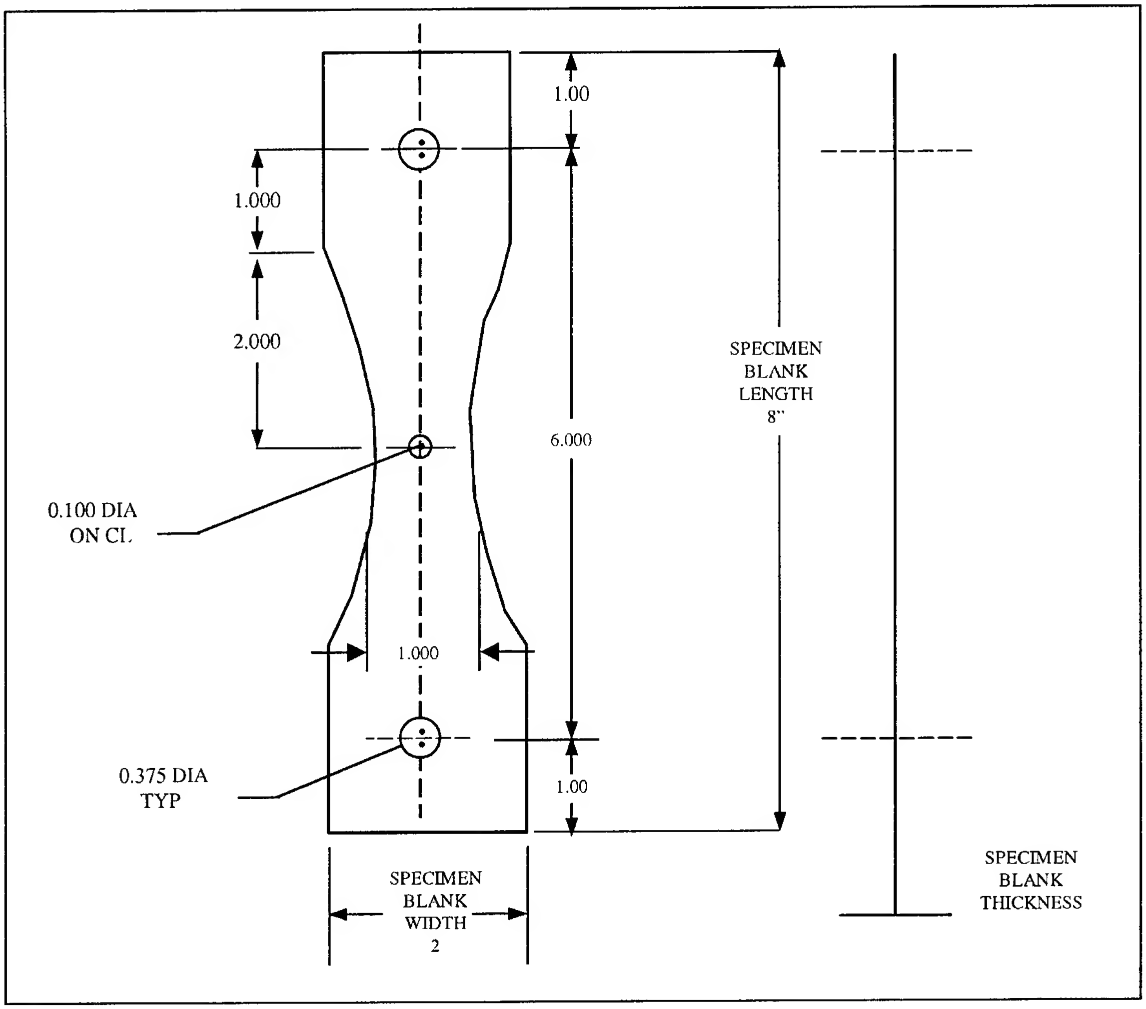

Figure 2: A Schematic of the Notched Specimen Design with a Drilled Central Hole of 0.100 in. Diameter

FATIGUE TEST RESULTS

Center hole fatigue test data for the Clad Al 2024-T3 at stress ratios (R) = +0.1 and +0.5 are presented in tables 3 and 4. The corresponding data for Clad Al 7075-T6 are presented in tables 5 and 6. Data are shown graphically in figures 3, 4, 5, and 6. The distribution of the data on these S-N diagrams shows similar behavior for both the FLASHJET® and the baseline specimens. In most cases, the FLASHJET® specimen lives fall within the scatter of the baseline tests. In order to better quantify the comparison, a statistical evaluation was performed using the Students T-test at a confidence interval of 95%. The results of these tests for all four data sets are presented in table 7. The data passed the T-test for all of the 2024-T3 specimens and for the three lower stress amplitudes for the 7075-T6. This means that within a 95% confidence interval, neither group has a higher mean value; i.e., the FLASHJET® stripped group and the corresponding baseline group have equivalent fatigue lives. For the highest stress amplitude (40Ksi) 7075-T6 group, the stripped specimens show a higher value than the baseline. It should

be noted that typical rotary wing fatigue methodology uses a "scatter factor" of 2 on fatigue strength to account for the scatter observed in typical test data. The FLASHJET® data will be bounded by this criteria as well. In summary, the FLASHJET® life cycle stripped specimens showed similar fatigue behavior to the baseline material and did not show any statistically significant degradation in fatigue life.

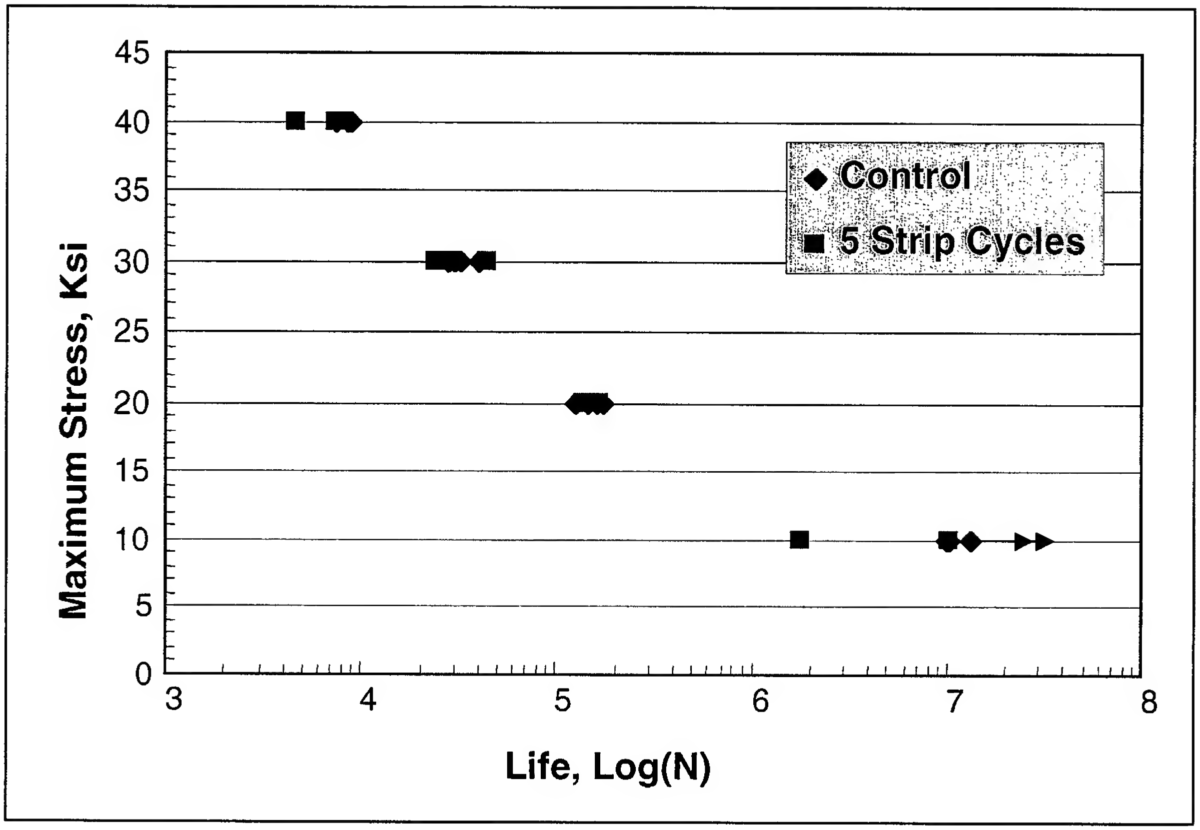

Figure 3: Aluminum 2024-T3 Center Hole Fatigue Life, R = 0.1

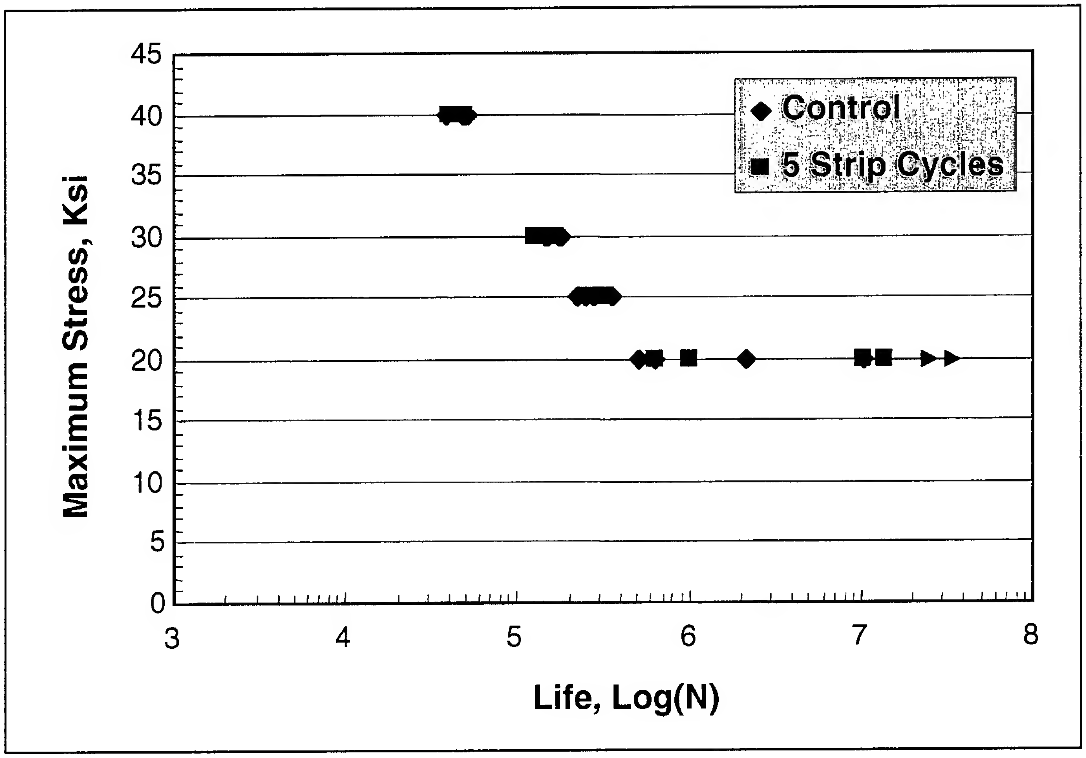

Figure 4: Aluminum 2024-T3 Center Hole Fatigue Life, R = 0.5

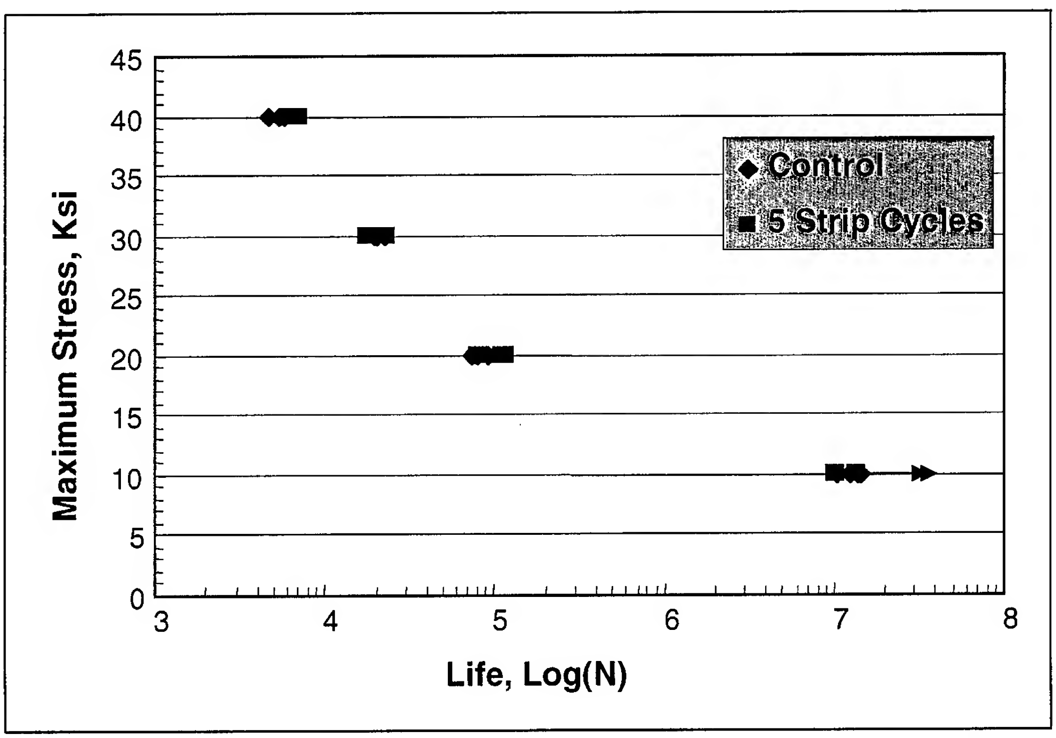

Figure 5: Aluminum 7075-T6 Center Hole Fatigue Life, R = 0.1

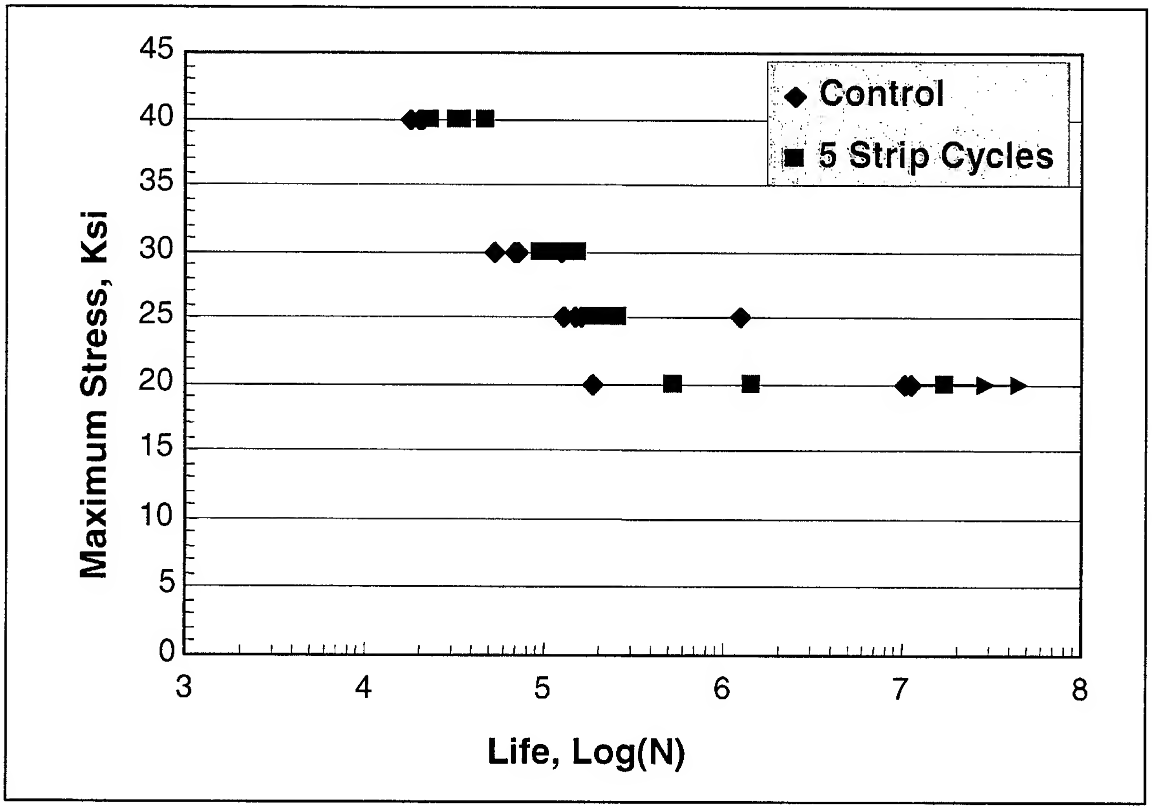

Figure 6: Aluminum 7075-T6 Center Hole Fatigue Life, R = 0.5

Table 3: Center Hole Fatigue Test Results, 2024 Al, R=0.1

Paint Condition	Maximum Stress	Maximum Load (lb)	Minimum Load (lb)	Specimen ID	Cycles at 40 Hz
A-Control	40	1,005	101	2-2A-2	7,442
		1,004	100	2-5A-2	8.972
		1,006	101	2-7A-2	8,627
		1,006	101	2-3A-2	8,857
C-Stripped 5X	40	1,006	101	2-2C-4	4,741
				2-8C-1	7,410
				2-5C-2	7,847
				2-2C-3	7,714
				2-13C-4	7,127
A-Control	30	754	74	2-6A-3	39,929
		755	75	2-9A-1	30,408
		755	75	2-9A-4	27,608
		755	75	2-8A-2	32,025
C-Stripped 5X	30	755	75	2-8C-4	24,666
				2-8C-2	30,615
				2-9C-1	44,508
				2-3C-2	28,100
A-Control	20	503	50	2-10A-4	126,649
				2-9A-3	173,515
				2-1A-3	163,970
				2-1A-1	147,424
C-Stripped 5X	20	503	50	2-3C-4	141,938
				2-5C-1	168,236
				2-4C-3	153,498
				2-3C-2	143,788
A-Control	10	252	25	2-8A-1	10,230,164
				2-4A-4	13,554,939
				2-4A-3	10,503,763
				2-4A-2	10,332,741
C-Stripped 5X	10	252	25	2-13C-1	10,608,870
				2-9C-2	1,772,338
				2-8C-4	10,325,921

Table 4: Center Hole Fatigue Test Results, 2024A1, R=0.5

Paint Condition	Maximum Stress	Maximum Load (lb)	Minimum Load (lb)	Specimen ID	Cycles at 40 Hz
A-Control	40	1,006	503	2-7A-3 2-6A-1 2-6A-4 2-7A-2	38,586 48,136 49,157 52,180
C-Stripped 5X	40	1,006	503	2-9C-4 2-4C-1 2-13C-3 2-4C-2	40,676 49,722 40,182 50,412
A-Control	30	755	377	2-9A-2 2-1A-3 2-1A-4 2-2A-1 2-8A-3	177,583 152,160 153,824 180,124 146,237
C-Stripped 5X	30	755	377	2-2C-2 2-6C-1 2-8C-3 2-5C-4	128,473 151,659 155,252 154,512
A-Control	25	629	314	2-10A-2 2-10A-1 2-2A-3 2-7A-4	355,833 222,672 254,720 274,353
C-Stripped 5X	25	629	314	2-9C-3 2-4C-4 2-3C-1 2-6C-2	336,183 288,209 259,735 269,400
A-Control	20	503	252	2-5A-3 2-3A-4 2-8A-4 2-4A-1	10,377,420 2,146,244 520,210 644,783
C-Stripped 5X	20	503	252	2-2C-1 2-6C-3 2-3C-3 2-13C-2*	641,270 10,333,541 13,788,111 1,019,112

*Specimen (2-13C-2) not used in statistical analysis. Test stopped prior to failure.

Table 5: Center Hole Fatigue Test Results, 7075A1, R=0.1

Paint Condition	Maximum Stress	Maximum Load (lb)	Minimum Load (lb)	Specimen ID	Cycles at 40 Hz
A-Control	40	946	95	7-2A-4	5,474
				7-8A-3	4,746
				7-9A-2	5,885
				7-3A-1	5,737
C-Stripped 5X	40	946	95	7-13C-2	7,093
				7-13C-1	6,938
				7-4C-4	7,231
				7-9C-3	6,068
A-Control	30	709	71	7-3A-4	20,614
				7-9A-3	19,573
				7-8A-2	20,639
				7-9C3	22,254
C-Stripped 5X	30	709	71	7-8C-1	17,811
				7-9C-2	20,000
				7-13C-4	18,134
				7-8C-3	23,727
A-Control	20	473	47	7-1A-1	91,787
				7-4A-4	78,845
				7-7A-3	78,900
				7-3A-2	73,585
C-Stripped 5X	20	473	47	7-2C-2	82,389
				7-2C-1	116,427
				7-6C-4	79,536
				7-13C-3	110,634
A-Control	10	236	24	7-10A-1	12,418,411
				7-1A-2	13,777,141
				7-8A-4	10,349,908
				7-3A-3	14,177,322
C-Stripped 5X	10	236	24	7-9C-4	13,449,139
				7-5C-1	10,205,523
				7-8C-2	13,818,446
				7-7C-3	10,268,125

Table 6: Center Hole Fatigue Test Results, 7075A1, R=0.5

Paint Condition	Maximum Stress	Maximum Load (lb)	Minimum Load (lb)	Specimen ID	Cycles at 40 Hz
A-Control	40	946	473	7-1A-3	18,455
				7-2A-2	18,298
				7-4A-1	21,068
				7-7A-4	20,141
C-Stripped 5X	40	946	473	7-5C-4	32,660
				7-2C-4	23,788
				7-7C-2	48,204
				7-4C-1	34,916
A-Control	30	709	355	7-5A-3	72,765
				7-8A-1	68,147
				7-11A-2	123,308
				7-11A-4	53,287
C-Stripped 5X	30	709	355	7-6C-1	144,862
				7-4C-3	111,668
				7-6C-2	153,653
				7-7C-4	96,696
A-Control	25	589	295	7-4A-3	164,504
				7-10A-2	1,227,813
				7-10A-4	128,257
				7-2A-1	149,307
C-Stripped 5X	25	589	295	7-6C-3	184,414
				7-8C-4	2,844,216
				7-4C-2	262,047
				7-7C-1	243,930
				7-2C-4	204,830
A-Control	20	473	236	7-5A-2	10,199,918
				7-9A-4	187,901
				7-10A-3	10,986,714
C-Stripped 5X	20	473	236	7-5C-5	17,190,968
				7-5C-2	1,453,952
				7-9C-1	539,214

Table 7: - Summary of Confidence Intervals and T-Test Results

2024 Al, R=0.5

Alloy	Stress Ratio	Max. Stress	Paint/Strip Condition	Cycles to Failure Mean Log	Cycles to Failure Std. Dev. Log	95% Confidence Interval Minimum	95% Confidence Interval Maximum	T-Test Result (95% Confidence)
2024 Al	0.5	40	Baseline Stripped 5X	4.669 4.653	0.057 0.054	4.578 4.568	4.761 4.739	OK
2024 Al	0.5	30	Baseline Stripped 5X	5.208 5.167	0.042 0.039	5.156 5.105	5.260 5.230	OK
2024 Al	0.5	25	Baseline Stripped 5X	5.436 5.458	0.086 0.050	5.300 5.379	5.572 5.537	OK
2024 Al	0.5	20	Baseline Stripped 5X	6.218 6.492	0.597 0.682	5.269 5.407	7.168 7.577	OK

2024 Al, R=0.1

Alloy	Stress Ratio	Max. Stress	Paint/Strip Condition	Cycles to Failure Mean Log	Cycles to Failure Std. Dev. Log	95% Confidence Interval Minimum	95% Confidence Interval Maximum	T-Test Result (95% Confidence)
2024 Al	0.1	40	Baseline Stripped 5X	3.927 3.836	0.038 0.091	3.867 3.723	3.987 3.949	OK
2024 Al	0.1	30	Baseline Stripped 5X	4.508 4.494	0.068 0.110	4.400 4.319	4.616 4.669	OK
2024 Al	0.1	20	Baseline Stripped 5X	5.181 5.180	0.060 0.034	5.086 5.127	5.277 5.234	OK
2024 Al	0.1	10	Baseline Stripped 5X	7.044 6.763	0.059 0.445	6.951 5.656	7.138 7.869	OK

7075 Al, R=0.5

Alloy	Stress Ratio	Max. Stress	Paint/Strip Condition	Cycles to Failure Mean Log	Cycles to Failure Std. Dev. Log	95% Confidence Interval Minimum	95% Confidence Interval Maximum	T-Test Result (95% Confidence)
7075 Al	0.5	40	Baseline Stripped 5X	4.289 4.529	0.030 0.126	4.242 4.329	4.336 4.729	Stripped > Baseline
7075 Al	0.5	30	Baseline Stripped 5X	4.878 5.095	0.153 0.095	4.634 4.944	5.122 5.246	OK
7075 Al	0.5	25	Baseline Stripped 5X	5.397 5.567	0.464 0.499	4.659 4.948	6.135 6.187	OK
7075 Al	0.5	20	Baseline Stripped 5X	6.441 6.377	1.011 0.774	3.930 4.453	8.953 8.300	OK

Note: 1 - "Stripped>Baseline" means that we are 95% confident that the interval from .082 to .398 contains the difference of the mean logarithms between stripped and baseline specimen groups.

7075 Al, R=0.1

Alloy	Stress Ratio	Max. Stress	Paint/Strip Condition	Cycles to Failure Mean Log	Cycles to Failure Std. Dev. Log	95% Confidence Interval Minimum	95% Confidence Interval Maximum	T-Test Result (95% Confidence)
7075 Al	0.1	40	Baseline Stripped 5X	3.736 3.834	0.042 0.034	3.669 3.779	3.802 3.888	Stripped > Baseline
7075 Al	0.1	30	Baseline Stripped 5X	4.317 4.296	0.023 0.057	4.280 4.206	4.353 4.387	OK
7075 Al	0.1	20	Baseline Stripped 5X	4.906 4.982	0.041 0.085	4.841 4.846	4.970 5.118	OK
7075 Al	0.1	10	Baseline Stripped 5X	7.100 7.072	0.062 0.072	7.002 6.958	7.198 7.187	OK

Other General Notes:

- "OK" means that with 95% confidence, neither group has a higher mean value.
- T-Test determines confidence interval for difference in means assuming equal variances.

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SUMMARY/CONCLUSIONS

This program evaluated the effects of FLASHJET® life cycle paint stripping on the high cycle fatigue behavior of two aluminum alloys used for fatigue critical helicopter structure. Based on the completion of five repeat paint and strip cycles, the fatigue life of 0.025 in. thick 2024-T3 or 7075-T6 aluminum is not degraded by stripping to the substrate with the FLASHJET® paint stripping process, when operated within the process parameters operating range tested.

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